FEEDING AGGREGATIONS OF BOTTLENOSE DOLPHINS AND SEABIRDS IN COCKBURN SOUND, WESTERN AUSTRALIA

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ABSTRACT

Cockburn Sound is the most intensively-utilised marine area in Western Australia, with further development planned. Information on the foraging ecology of bottlenose dolphins and seabirds in Cockburn Sound will aid conservation efforts. We observed dolphins and 7 seabird species at large multi-species feeding aggregations in Cockburn Sound between 2000–2. Dolphins and Pied Cormorants were the most abundant species at the aggregations, with a mean abundance of 21.4 (±7.4) dolphins and the abundance of cormorants sometimes in exeess of 200 individuals. Aggregations consistently occurred within the Kwinana Shelf in the northeastern corner of Cockburn Sound and were more common during the autumn-spring period. These aggregations most likely targeted schools of forage fish based on observations of prey and the substantial biomass of prey required to sustain the large number of predators present. These aggregations are an important feature of the foraging ecology of dolphins and seabirds in Cockburn Sound, and impact assessment should consider the impaet of development on habitat for forage fish on the Kwinana Shelf.

INTRODUCTION

Cockburn Sound is the only well-protected embayment for over 1000 kilometres of coastline, and provides most of the sheltered inshore marine habitat along the lower west coast of Australia (Penn 1977, Valesini *et al.* 2003). It has also been the most intensively utilised marine area in Western Australia for the past half-century, with further development planned (EPA 1998, DAL 2001, DOE 2005). Intensive study of the Cockburn Sound ecosystem (see DEP 1996, DAL 2001) has documented substantial ecological change, especially changes in seagrass and finfish communities (e.g.

Dybdahl 1979, Scott *et al.* 1986, Kendrick *et al.* 2000, Vanderklift and Jacoby 2003). However, little is known about the foraging ecology of top-level predators in the Cockburn Sound ecosystem (Cannell 2004, Finn 2005, Ropert-Coudert *et al.* 2006). Uncertainty therefore exists over how large-scale infrastructure developments proposed for Cockburn Sound will impact on dolphins, seabirds, and their prey (EPA 1998, 2004, 2006, Finn 2005).

A resident community of ~75 Bottlenose Dolphins (*Tursiops* sp.[1]) inhabits Cockburn Sound year-round (Finn 2005). Inshore bottlenose dolphins typically forage individually or in small groups hunting for individual prey items or small schools of prey associated with vegetated habitats, bathymetric gradients, tidal fronts, or other environmental features (Barros and Wells 1998, Connor *et al.* 2000, Heithaus and Dill 2002, Ingram and Rogan 2002, Mendes *et al.* 2002, Lewis and Schroeder 2003, Hastie *et al.* 2004). However, dolphins may also aggregate to exploit large schools of 'forage fish' such as clupeoids (e.g. sardines, sprat, pilchards, herring) and engraulids (anchovies) occurring within nearshore areas (Saayman and Tayler 1979, Würsig and Würsig 1979, Wells *et al.* 1980, Cockcroft and Ross 1990, Bräger 1998a,b, Vaughn *et al.* 2007). Both solitary or weakly-schooling finfish species and large schools of forage fish occur within Cockburn Sound (Penn 1977, Dybdahl 1979, DOF 2007), suggesting that dolphins in Cockburn Sound should utilise both prey types, and form aggregations to feed on forage fish when they are available.

Seabird species occurring within Cockburn Sound include Silver Gulls (*Larus novaehollandiae*), Pied Cormorants (*Phalacrocorax varius*), Australian Pelicans (*Pelecanus conspicillatus*), Australasian Gannets (*Morus serrator*), White-bellied Sea Eagles (*Haliaeetus leucogaster*), Crested Terns (*Sterna bergii*), Lesser Crested Terns (*Sterna bengalensis*), and Little Penguins (*Eudyptula minor*) (DEP 1996, Cannell 2004). These seabirds may inhabit Cockburn Sound year-round, seasonally (e.g. during breeding seasons), or as transient migrants (Cannell 2004). Breeding populations of Little Penguins, Pied Cormorants, Crested Terns, and other species occur on the offshore islands of Penguin Island (5km south of Cockburn Sound) and Carnac Island (2 km north of Cockburn Sound), with smaller populations on Garden Island at the western margin of Cockburn Sound (Dunlop and Storr 1981, Wooller and Dunlop 1981, Dunlop *et al.*

[1] The systematics of the *Tursiops* genus in Perth metropolitan waters has not been adequately described (Finn 2005). Both the Bottlenose Dolphin, *T. truncatus* and the Indo-Pacific Bottlenose Dolphin, *T.aduncus* haplotypes occur in this area.

1988, Dunlop and Wooller 1990, Cannell 2004).

While the foraging ecologies of seabirds differ, forage fish are important prey for many Western Australian seabird populations (including breeding populations in the Perth area) (Klomp and Wooller 1988, Dunlop and Wooller 1990, Wooller *et al.* 1991, Dunlop 1997, Surman and Wooller 2000, Lenanton *et al.* 2003, Surman and Wooller 2003, Cannell 2004), and for seabirds in southern Australia more generally (Croxall 1987, Bunce 2001, 2004, Chiaradia *et al.* 2002, 2003, Dann *et al.* 2003). Species of forage fish occurring within Cockburn Sound include: (a) clupeoids (Scaly Mackerel *Amblygaster postera*, Maray *Etrumeus jacksoniensis*, Whitebait/ Sandy Sprat *Hyperlophus vittatus*, Perth Herring *Nematalosa vlaminghi*, Australian Pilchard *Sardinops* sp., Blue Sprat *Sprattelliodes robustus*) and (b) engraulids (Anchovy *Engraulis australis*) (Dybdahl 1979). The composition of finfish assemblages varies across habitats within Cockburn Sound (Dybdahl 1979, Scott *et al.* 1986, Vanderklift and Jacoby 2003, DOE 2005). Snapper, pilchards, bonito, whiting, squid, cuttlefish, butterfish, and skipjack use the Central Basin; whiting, anchovies, and sprat utilise areas of shallow sandy seabed; while leatherjackets, wrasse, herring, and garfish inhabit seagrass meadows (Penn 1977, DOE 2005). However, there is little published information about the seasonal presence and distribution of forage fish within Cockburn Sound (Dybdahl 1979, DOF 2007).

Here we document a previously undescribed feature of the foraging ecology of bottlenose dolphins and seabirds in Cockburn Sound—the occurrence of large multi-species feeding aggregations. We document the characteristics of feeding aggregations of dolphins and seabirds in Cockburn Sound, including spatial and temporal patterns, species presence and abundance, and feeding behaviours, and discuss probable prey species. We also suggest the implications of these aggregations for environmental management in Cockburn Sound.

METHODS

Study Area and Population

Cockburn Sound (32° 12' S, 115° 44' E) contains three broad habitats: 1) shallow (<10m) seagrass meadows along the northern, western, and southern margins; 2) a deep (18–20m) Central Basin with silt substrate; and 3) the Kwinana Shelf (also known as the Eastern Flats), an area of intermediate depth (4–12m) along the northeastern margin (Figure 1). While the Central Basin and seagrass meadows are relatively homogenous in substrate and bathymetry, the Kwinana Shelf is more heterogenous, with habitats ranging from patches of limestone reef and remnant sea-

grass, shipping channels, jetties, rock break-waters, to stretches of sandy beach (DEP 1996, Finn 2005).

Observations of foraging aggregations

Data on feeding aggregations of dolphins and seabirds were collected incidentally during a study of dolphin ecology in Cockburn Sound from 2000–2. In 2000–1 we observed feeding aggregations on an opportunistic basis as we searched throughout Cockburn Sound for dolphins. Surveys were conducted year-round, averaging 2–3 survey days per week from 2000–1. From April–October 2002 we searched for dolphins exclusively on the Kwinana Shelf (n = 47 survey days) and collected incidental data for any feeding aggregations observed. Most searches for dolphins began just after first light, with search effort generally concluding by mid-day, particularly during summer.

We defined feeding aggregations as temporary assemblages of ≥10 dolphins feeding within the same general area. By definition, this excluded aggregations of feeding seabirds with no dolphins present (as sometimes occurred). For the larger aggregations it was necessary to estimate the number of dolphins present because the aggregations were highly mobile and often widely dispersed, and the surfacing patterns of feeding dolphins were erratic. During observations of feeding aggregations, we recorded: time and location, dolphin and seabird foraging behaviour, and seabird species present. We did not estimate the number of seabirds present or record the duration of feeding aggregations because: dolphins were our primary study interest, we often observed aggregations that were already underway, and we typically departed before aggregations ended (to search for other dolphins). We include only the first aggregation observed in a day in our analyses to ensure that aggregations were independent of each other.

RESULTS

Spatial and Temporal Patterns

We observed 29 feeding aggregations in 2000 (n = 7) and 2001 (n = 22) on an opportunistic basis during searches for dolphins throughout Cockburn Sound (Figure 1). 62% (n = 18) of these aggregations were in the austral autumn-spring period (May–September) and 24% (n = 7) were in summer months (November–March). With the exception of one aggregation near Garden Island, all observations of foraging aggregations in 2000 and 2001 were located on the Kwinana Shelf or at the eastern margin of the Central Basin near the Kwinana Shelf. We observed 33 foraging aggregations on the Kwinana Shelf from April to October 2002 (Figure 1). Foraging aggregations were observed on 70% of survey days (n = 47), and in at least 50%

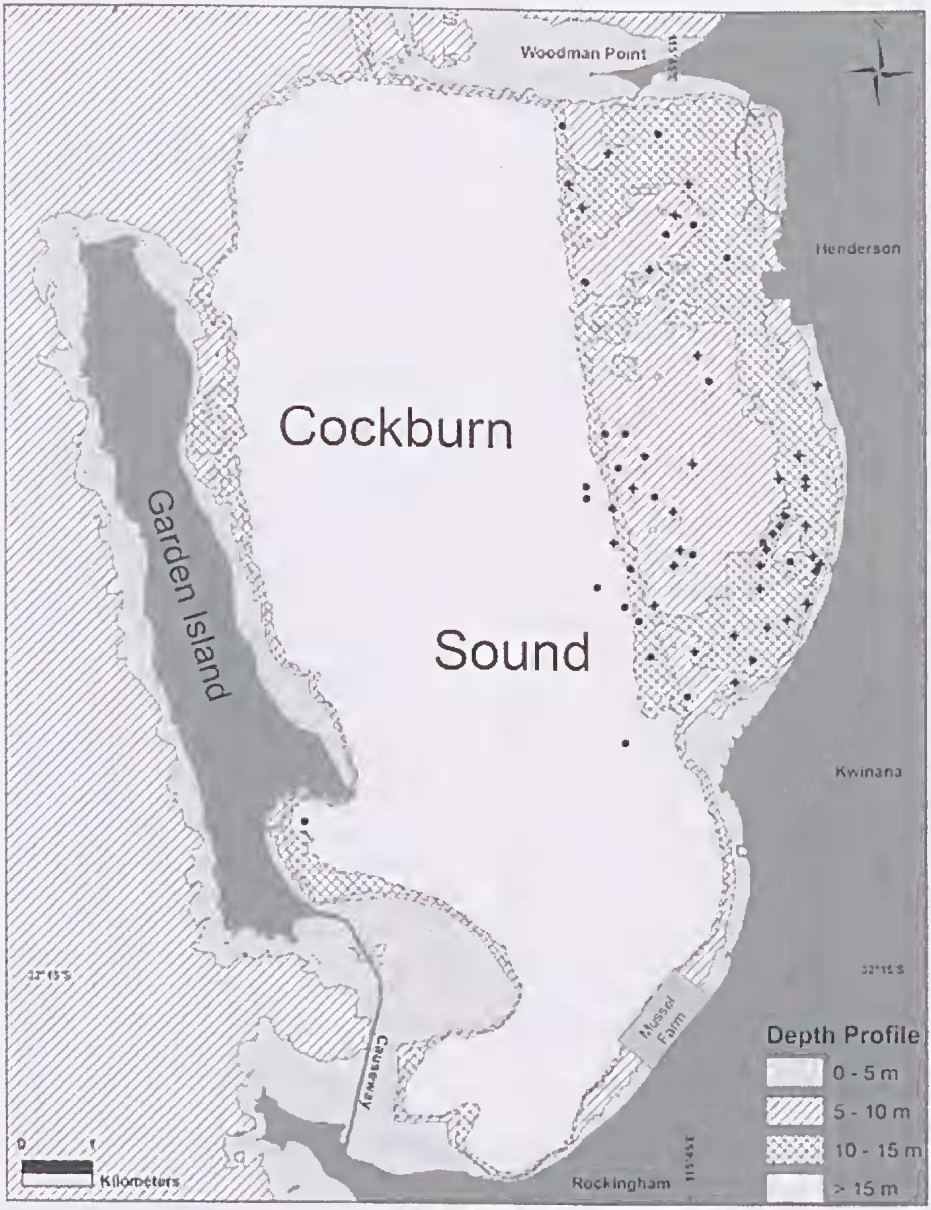

Figure 1. Distribution of foraging aggregations: (a) 2000 and 2001 [●] and (b) 2002 [+]

Table 1. Number of aggregations observed per month in 2002 [total number of survey days in parentheses]

Apr	May	Jun	Jul	Aug	Sep	Oct	Total
4 [8]	5 [8]	5 [7]	5 [5]	9 [11]	3 [4]	2 [4]	33 [47]

of survey days during each month (Table 1). Most aggregations occurred on the southern half of the Kwinana Shelf, with a concentration of observations along the eastern margin between the Alcoa jetty and James Point.

Species Presence and Abundance

The abundance of dolphins at feeding aggregations varied. 45% (n = 14) of aggregations were estimated to include 10–19 dolphins, 48% (n = 15) to include 20–29 dolphins, and 6% (n = 2) to include 30 or more dolphins. The mean of the 'best' estimates of aggregation size was 21.4 + 7.4 dolphins (median = 22; range = 10 – 40). We observed 7 species of seabird at feeding aggregations: Silver Gull, Pied Cormorant, Australian Pelican, Australasian Gannet, White-bellied Sea Eagle, Crested Tern, and Lesser Crested Tern. Pied Cormorants and Silver Gulls were present at all foraging aggregations. Terns (Crested or Lesser Crested) and Australasian Gannets were observed at 61% (n = 19) and 39% (n = 12) of aggregations respectively. We observed the other seabird species infrequently, and did not observe Little Penguins at the aggregations. Pied Cormorants were the most abundant species, with incidental estimates of >200 individuals recorded for some aggregations.

Foraging Behaviours

During early morning searches in the 2002 study, we commonly observed dolphins moving onto the Kwinana Shelf from the Central Basin individually or in small travelling groups. When a feeding aggregation initiated on the Kwinana Shelf, these individuals or groups moved rapidly towards the aggregation even if the aggregation was several kilometres distant. Aggregations quickly developed into mobile assemblages of feeding dolphins and seabirds, typically progressing along the Shelf, covering upwards of 1–2 km an hour in some cases. Foraging activity generally ceased or decreased when aggregations reached the western margin of the Kwinana Shelf and entered the deeper (18–20m) waters of the Central Basin, suggesting that prey schools 'sounded' or dispersed to avoid predators.

Individual dolphins tended to mill in one area dispersed more than 10m, sometimes clustering into small, closely-spaced (<10m) sub-groups diving in nearly the

same location. In the 2002 study we observed rapid surfacing patterns involving leaps (full body clearance from the water) or porpoises (partial body clearance from the water) in 58% of aggregations (n = 18 aggregations), typical of rapid pursuit. The foraging behaviour of seabirds was species-specific. Groups of cormorants were typically strung out in an extended line and engaged in a cyclical 'leapfrog' foraging behaviour in which cormorants at the back of the line flew ahead of diving cormorants at the head of the line. Gannets and terns utilised plunge-diving to capture fish. Silver gulls were rarely observed to directly capture prey items, instead kleptoparasitising cormorants and terns.

Dolphins were not observed consuming prey, indicating that prey items were consumed beneath the surface. Captured prey for seabirds were typically small (<25 cm length) and clupeoid (long and thin) in shape, but we were unable to determine prey type to species.

DISCUSSION

Spatial and temporal patterns

This study indicates that feeding aggregations are a consistent, long-term feature of the foraging ecology of dolphins and seabirds in Cockburn Sound. We consistently observed feeding aggregations from 2000–2, and in each of the seven months that we surveyed the Kwinana Shelf in 2002. Feeding aggregations were also consistently observed during an earlier study of dolphins in Cockburn Sound from 1993–7 (R. Donaldson, Murdoch University, unpublished data). The aggregations appear to be strongly linked to features of the Kwinana Shelf, given the prevalence of observations there. We emphasise that, even in 2000–1 when we surveyed for dolphins throughout Cockburn Sound, feeding aggregations were predominantly associated with the Kwinana Shelf.

The findings suggest two temporal patterns. Firstly, in 2000–1 the majority of aggregations were observed during the austral autumn-spring period, suggesting an association between cooler water temperatures and the occurrence of aggregations. This pattern corresponds with the breeding seasons of some seabirds, such as Pied Cormorants (Dunlop and Storr 1981, Dunlop and Wooller 1986, Dunlop *et al.* 1988, Dunlop and Wooller 1990, Cannell 2004). The abundance of forage fish within nearshore ecosystems in WA shows considerable variability across species, seasons, and years; however, they are generally more abundant when water temperatures are cooler (Gaughan *et al.* 1990, Lenanton *et al.* 1991, Fletcher and Tregonning 1992, Fletcher *et al.* 1994, Caputi *et al.* 1996, Fletcher 1999, Gaughan *et al.* 2001). Secondly, our anecdotal observations of the apparent searching behaviour of dolphins

suggest that dolphins and possibly seabirds often sought to locate forage fish soon after sunrise. Further research would help to confirm seasonal and diel (i.e. 24-hour period) patterns, as our search effort for aggregations was not systematic and we also observed feeding aggregations later in the day.

Species presence and abundance

The feeding aggregations indicate an aggregative response to a clumped, high-density prey. In offshore environments, a low cost of locomotion and the ability to detect visual, acoustic (e.g. leaping dolphins, diving seabirds, feeding calls), and (for seabirds) olfactory feeding cues over long distances allow dolphins and seabirds to successfully exploit widely-dispersed or unpredictable prey patches (Croxall 1987, Connor *et al.* 2000, Janik 2000). These ecological traits would also work effectively within the circumscribed extent of Cockburn Sound, allowing dolphins and seabirds to locate and feed on forage fish when these prey were present and abundant. We did not observe aggregations of dolphins or seabirds during some periods between 2000–2, so the flexibility to feed in different areas or on a range of prey species is important for dolphins and at least some seabird species in Cockburn Sound.

Foraging behaviours

Seabirds and dolphins often feed in association with each other (Evans 1982, Bräger 1998a,b, Hawke and Dobinson 2001, Vaughn *et al.* 2007). During feeding aggregations, dolphins and seabirds may interact through interference competition in which the presence of one predator reduces the foraging efficiency of another, or through exploitation competition, where one predator removes a resource otherwise available for another (Shealer and Burger 1993, Acevedo-Gutiérrez 2002). In particular, the large (>200 individuals) abundances of Pied Cormorants sometimes present could have disrupted dolphin feeding, and or removed a substantial biomass of prey that dolphins could have consumed.

However, interactions between seabirds and dolphins may have been complex, and involved competition, mutualism, and or indirect effects (Dill *et al.* 2003). As aerial predators, seabirds may have located schools of forage fish on the Kwinana Shelf, and thus indirectly facilitated the capture of prey by dolphins; alternatively, seabirds may simply have used groups of feeding dolphins as cues for the location of prey schools. The feeding behaviour of seabirds could also have facilitated the capture of prey by dolphins. The leap-frogging behaviour of cormorants, for example, may have helped to corral schools of forage fish near the surface or within habitats where the schools were unable to sound.

Dolphins could also have played a similar role because of their ability to dive beneath prey schools. Further research could determine whether (and which) inter-specific interactions occur during feeding interactions.

Probable prey

The aggregations almost certainly targeted a species (or multiple species) of forage fish. Firstly, forage fish are small enough for dolphins to consume immediately after capture, which would explain why we did not see dolphins with prey at the surface. As dolphins cannot masticate, larger prey items must be fragmented prior to consumption by rubbing the prey item along the substrate or by tossing the prey item at the surface (H. Finn, personal observation). Secondly, we often observed cormorants and terns to bring prey items to the surface that were the size and shape of forage fish, although we could not determine species. While Pied Cormorants — the most abundant seabird at the aggregations — are typically benthic feeders, they are opportunistic predators and will utilise planktonic prey when it is available (Trayler *et al.* 1989, Kato *et al.* 2001, Quintana *et al.* 2004). Finally, forage fish are probably the only finfish taxa within Cockburn Sound that could obtain the schooling biomass to sustain the number of predators present at the feeding aggregations. From 1977–2001 the majority of the commercial finfish catch within Cockburn Sound was forage fish (DOF 2002, DOE 2005). It is also possible that dolphins and seabirds utilised several species of forage fish, as well as other prey species (e.g. squid, cuttlefish) that may have been present at the aggregations.

Forage fish offer several benefits as a food source for dolphins and seabirds in Cockburn Sound. Firstly, our observations on the Kwinana Shelf in 2002 suggest that when schools of forage fish are present, they provide a resource that is available on a near daily basis for several months. Secondly, the high-density and aggregative behaviour of forage fish schools may facilitate prey capture and increase intake rates, allowing for enhanced foraging efficiency. Finally, many species of forage fish have excellent nutritional qualities because of their high lipid content and energy density (Payne *et al.* 1999, Iverson *et al.* 2002). Such high-energy food may be particularly valuable to dolphins during the autumn-spring period. Captive Bottlenose Dolphins in the Perth area were observed to increase their intake rates during this period, suggesting that the energetic demands of dolphins increase when water temperatures are low (Cheal and Gales 1991, 1992). Many seabirds, including Pied Cormorants, also breed from autumn through spring, and the availability of forage fish could be one factor sustaining recent

increases in breeding populations of Pied Cormorants (and possibly) Silver Gulls at Penguin Island and Carnac Island (Rippey *et al.* 2002, CCWA and CALM 2003).

Further research could determine the relative importance of forage fish to the diet of dolphins and seabirds. On-going diet studies of the Little Penguin colony at Garden Island would be useful in this regard. Although we did not observe Little Penguins during feeding aggregations, recent satellite tracking data shows that penguins from Garden Island forage throughout Cockburn Sound (including the Kwinana Shelf), and thus are likely to prey on forage fish if they are available (B. Cannell, Murdoch University, personal communication).

Management implications

Our objective here was to document an important feature of dolphin and seabird foraging ecology in Cockburn Sound. Although the feeding aggregations appear to be an enduring ecological phenomenon in the Sound, their long-term continuity is not assured. The Kwinana Shelf is currently subject to intensive human use and is also a focal point for future industrial development, including the construction of extensive port facilities (EPA 1998, 2004, 2006, DAL 2001, DOE 2005). Little is known about the potential implications of further industrial development for resident finfish communities and for seasonal assemblages of forage fish. While localised effects (e.g. habitat loss from infrastructure construction) are a concern, the feeding aggregations also emphasise that the spatial and ecological integrity of the Kwinana Shelf as a whole may be important for fish assemblages. Fragmentation of the Shelf caused by land reclamation and the construction of breakwaters and harbours would, for example, sever linkages between nearshore areas and the broader Shelf environment (Vanderkift and Jacoby 2003, Hyndes 2004). We thus suggest that environmental impact assessment consider how modifications to the Kwinana Shelf could alter the suitability of this area for forage fish, and thus diminish an important prey for dolphins and seabirds.

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REFERENCES

ACEVEDO-GUTIÉRREZ, A. 2002. Interactions between marine predators: dolphin food intake is related to number of sharks. *Marine Ecology Progress Series* **240**: 267–271.

BARROS, N.B. and WELLS, R.S. 1998. Prey and feeding patterns of resident bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Journal of Mammalogy* **79**: 1045–1059.

BRÄGER, S. 1998a. Feeding associations between white-fronted terns and Hector's Dolphins in New Zealand. *The Condor* **100**: 560–562.

BRÄGER, S. 1998b. Behavioural ecology and population structure of Hector's dolphin (*Cephalorhynchus hectori*). PhD thesis, University of Otago, Dunedin, New Zealand.

BUNCE, A. 2001. Prey consumption of Australasian gannets (*Morus serrator*) breeding in Phillip Bay, southeast Australia, and potential overlap with commercial fisheries. *ICES Journal of Marine Science* **58**: 904–915.

BUNCE, A. 2004. Do dietary changes of Australasian gannets (*Morus serrator*) reflect variability in pelagic fish stocks? *Wildlife Research* **31**: 383–387.

CANNELL, B.L 2004. Distribution of the major marine fauna in Perth metropolitan area (Yanchep to Mandurah). Report No. MMS/CWC, LNE/MMP, SEMP, SIMP-79/2004. Marine Conservation Branch, WA Department of Conservation and Land Management, Perth.

CAPUTI, N., FLETCHER, W.J., PEARCE, A. and CHUBB, C.F. 1996. Effect of the Leeuwin Current on the recruitment of fish and invertebrates along the Western Australian coast. *Marine and Freshwater Research* **47**: 147–155.

CCWA and CALM. 2003. Carnac Island Nature Reserve Management Plan 2003. Management Plan 47. Conservation Commission Western Australia and WA Department of Conservation and Land Management, Perth.

CHEAL, A.J. and GALES, N.J. 1991. Body mass and food intake in captive, breeding bottlenose dolphins, *Tursiops truncatus*. *Zoo Biology* **10**: 451–456.

CHEAL, A.J. and GALES, N.J. 1992. Growth, sexual maturity, and food intake of Australian Indian Ocean bottlenose dolphins,

Tursiops truncatus, in captivity. *Australian Journal of Zoology* 40: 215–223.

CHIARADIA, A., DANN, P., JESSOP, R. and COLLINS, P. 2002. The diet of Crested Tern (*Sterna bergii*) chicks on Phillip Island, Victoria, Australia. *Emu* 102: 367–371.

CHIARADIA, A., COSTALUNGA, A. and KERRY, K. 2003. The diet of Little Penguins (*Eudyptula minor*) at Phillip Island, Victoria, in the absence of a major prey – pilchard (*Sardinops sagax*). *Emu* 103: 43–48.

COCKCROFT, V.G. and ROSS, G.J.B. 1990. Food and feeding of the Indian Ocean bottlenose dolphin off Southern Natal, South Africa. pp 295–308 in *The Bottlenose Dolphin*, S. Leatherwood and R.R. Reeves (ed's). Academic Press, New York, USA.

CONNOR, R.C., WELLS, R.S., MANN, J. and READ, A.J. 2000. The bottlenose dolphin: social relationships in a fission-fusion society. pp 91–126 in *Cetacean Societies: Field Studies of Dolphins and Whales*, J. Mann, R.C. Connor, P.L. Tyack, and H. Whitehead (ed's). University of Chicago Press, Chicago, USA.

CROXALL, J.P. (ed.) 1987. *Seabirds: Feeding Ecology and Role in Marine Ecosystems*. Cambridge University Press, Cambridge, England.

DAL. 2001. The state of Cockburn Sound—a pressure-state-response report. Report prepared for the Cockburn Sound Management Council by D.A. Lord and Associates, Pty. Ltd.

DANN, P., ARNOULD, J.P.Y., JESSOP, R. and HEALY, M. 2003. Distribution and abundance of seabirds in Western Port, Victoria. *Emu* 103: 307–313.

DEP. 1996. Southern metropolitan coastal waters study (1991–1994)—final report. WA Department of Environmental Protection, Perth.

DILL, L.M., HEITHAUS, M.R. and WALTERS, C.J. 2003. Behaviorally mediated indirect interactions in marine communities and their conservation implications. *Ecology* 84: 1151–1157.

DOE. 2005. Environmental Management Plan for Cockburn Sound and its Catchment. WA Department of Environment, Perth.

DOF. 2002. State of the fisheries report 2001/2002. Fisheries Research Division, WA Department of Fisheries, Perth.

DOF. 2007. State of the fisheries report 2006/2007. Fisheries Research Division, WA Department of Fisheries, Perth.

DUNLOP, J.N. 1997. Foraging range, marine habitat and diet of bridled terns breeding in Western Australia. *Corella* 21: 77–82.

DUNLOP, J.N. and STORR, G.M. 1981. Seabird Islands No. 111. Carnac Island, Western Australia. *Corella* 5: 71–74.

DUNLOP, N. and WOOLLER, R.D. 1986. Range extensions and the breeding seasons of seabirds in south-western Australia. *Records of the Western Australian Museum* 12: 389–394.

DUNLOP, J.N., N.I. KLOMP and

WOOLLER, R.D.. 1988. Seabird Islands No. 188: Penguin Island, Shoalwater Bay, Western Australia. *Corella* 12: 93–98.

DUNLOP, N. and WOOLLER, R.D. 1990. The breeding seabirds of southwestern Australia: trends in species, populations and colonies. *Corella* 14: 107–112.

DYBDAHL, R.E. 1979. Cockburn Sound—technical report on fish productivity. Report No. 4. WA Department of Conservation and Environment, Perth.

EPA. 1998. The marine environment of Cockburn Sound. Bulletin 907. WA Environmental Protection Authority, Perth.

EPA. 2004. James Point Stage One Port, Kwinana: report and recommendations of the Environmental Protection Authority. Bulletin 1141. WA Environmental Protection Authority, Perth.

EPA. 2006. Fremantle Ports Outer Harbour Project. Bulletin 1230. WA Environmental Protection Authority, Perth.

EVANS, P.G.H. 1982. Associations between seabirds and cetaceans: a review. *Mammal Review* 12: 187–206.

FINN, H.C. 2005. Conservation biology of bottlenose dolphins (*Tursiops* sp.) in Perth metropolitan waters. PhD thesis, Murdoch University, Perth. (Available on-line through the Australian Digital Theses Program http://adt.caul.edu.au/)

FLETCHER, W.J. 1999. Vertical distribution of pilchard (*Sardinops sagax*) eggs and larvae off Southern Australia. *Australian Journal of Marine and Freshwater Research* 50: 117–122.

FLETCHER, W.J. and TREGONNING, R.J. 1992. Distribution and timing of spawning by the Australian pilchard (*Sardinops sagax neopilchardus*) off Albany, Western Australia. *Australian Journal of Marine and Freshwater Research* 43: 1437–1449.

FLETCHER, W.J., TREGONNING, R.J. and SANT, G.J. 1994. Interseasonal variation in the transport of pilchard eggs and larvae off southern Western Australia. *Marine Ecology Progress Series* 111: 209–224.

GAUGHAN, D.J., BAUDAINS, G.A., MITCHELL, R.W.D. and LEARY, T.I. 2001. Pilchard (*Sardinops sagax*) nursery areas and recruitment process assessment between different regions in southern Western Australia. Fisheries Research Report No. 131. Fisheries Research Division, WA Department of Fisheries, Perth.

GAUGHAN D.J., NEIRA F.J., BECKLY, L.E., and POTTER I.C. 1990. Composition, seasonality and distribution of ichthyoplankton in the lower Swan estuary. *Australian Journal of Marine and Freshwater Research* 41: 529–543.

HASTIE, G.D., WILSON, B., WILSON, L.J., PARSONS, K.M. and THOMPSON, P.M. 2004. Functional mechanisms underlying cetacean distribution patterns: hotspots for bottlenose dolphins are linked to foraging. *Marine Biology* 144: 397–403.

HAWKE, D.J. and DOBINSON, J. 2001. Some seabird associations with dusky dolphins (*Lagenorhynchus obscurus*) at Kaikoura and with orca (*Orcinus orca*) at Nelson, New Zealand. *Notornis* 48: 56–58.

HEITHAUS, M.R. and DILL, L.M. 2002. Food availability and tiger shark predation risk influence bottlenose dolphin habitat use. *Ecology* 83: 480–491.

HYNDES, G. 2004. Fish habitat in the nearshore regions of Cockburn Sound. Summary paper prepared for the Cockburn Sound Management Council by Glenn Hyndes, School of Natural Sciences, Edith Cowan University.

INGRAM, S.I. and ROGAN, E. 2002. Identifying critical areas and habitat preferences of bottlenose dolphins (*Tursiops truncatus*). *Marine Ecology Progress Series* 244: 247–255.

IVERSON, S.J., FROST, K.J. and LANG, S. 2002. Fat content and fatty acid composition of forage fish and invertebrates in Prince William Sound, Alaska: factors contributing to among and within species variability. *Marine Ecology Progress Series* 241: 161–181.

KATO, A., WATANUKI, Y. and NAITO, Y. 2001. Foraging and breeding performance of Japanese cormorants in relation to prey type. *Ecological Research* 16: 745–758.

JANIK, V.M. 2000. Food-related bray calls in wild bottlenose dolphins (*Tursiops truncatus*). *Proceedings of the Royal Society of London B* 267: 923–927.

KENDRICK, G.A., HEGGE, B.J., WYLLIE, A., DAVIDSON, A. and LORD, D.A. 2000. Changes in seagrass cover on Success and Parmelia Banks, Western Australia between 1965–1995. *Estuarine, Coastal, and Shelf Science* 50: 341–353.

KLOMP, N.I. and WOOLLER, R.D. 1988. Diet of Little Penguins *Eudyptula minor* from Penguin Island, Western Australia. *Australian Journal of Marine and Freshwater Research* 39: 633–639.

LENANTON, R.C., JOLL, L., PENN, J. and JONES, K. 1991. The influence of the Leeuwin Current on coastal fisheries in Western Australia. *Journal of the Royal Society of Western Australia* 74: 101–114.

LENANTON, R.C.J., VALESINI, F., BASTOW, T.P., NOWARA, G.B., EDMONDS, J.S. and CONNARD, M.N. 2003. The use of stable isotope ratios in whitebait otolith carbonate to identify the source of prey for Western Australian penguins. *Journal of Experimental Marine Biology and Ecology* 291: 17–27.

LEWIS, J.S. and SCHROEDER, W.W. 2003. Mud plume feeding, a unique foraging behaviour of the bottlenose dolphin in the Florida Keys. *Gulf of Mexico Science* 21: 92–97.

MENDES, S., TURRELL, W., LÜTKEBOHLE, T. and THOMPSON, P. 2002. Influence of the tidal cycle and a tidal intrusion front on the spatio-temporal distribution of coastal bottlenose dolphins. *Marine Ecology Progress Series* 239: 221–229.

PAYNE, S.A., JOHNSON, B.A and

OTTO, R.S. 1999. Proximate composition of some north-eastern forage fish species. *Fisheries Oceanography* 8: 159–177.

PENN, J.W. 1977. Trawl caught fish and crustaceans from Cockburn Sound. Fisheries and Wildlife Report No. 20. WA Department of Fisheries and Wildlife, Perth.

QUINTANA, F., YORIO, P., LISNIZER, N., GATTO, A. and SORIA, G. 2004. Diving behavior and foraging areas of the Neotropic Cormorant at a marine colony in Patagonia, Argentina. *The Wilson Bulletin* 116: 83–88

RIPPEY, E., RIPPEY, J.J. and DUNLOP, J.N. 2002. Increasing numbers of pied cormorants breeding on the islands off Perth, Western Australia and consequences for the vegetation. *Corella* 26: 61–64.

ROPERT-COUDERT, Y., KATO, A., WILSON, R.P. and CANNELL, B. 2006. Foraging strategies and prey encounter rate of free-ranging Little Penguins. *Marine Biology* 149: 139–148.

SAAYMAN, G.S. and TAYLER, C.K. 1979. The socioecology of humpback dolphins (*Sousa* sp.). pp 165–226 in *Behaviour of Marine Animals. Volume 3: cetaceans*, H.E. Winn and B.L. Olla (ed's). Plenum, New York, USA.

SCOTT, J.K., DYBDAHL, R. and WOOD, W.F. 1986. The ecology of *Posidonia* seagrass fish communities in Cockburn Sound, Western Australia. Technical Series 11. WA Department of Conservation and Environment, Perth.

SHEALER, D.A. and BURGER, J. 1993. Effects of interference competition on the foraging activity of tropical roseate terns. *The Condor* 95: 322–329

SURMAN, C.A. and WOOLLER, R.D. 2000. Seabirds off the south-western coast of Australia. *Emu* 100: 312–7.

SURMAN, C.A. and WOOLLER, R.D. 2003. Comparative foraging ecology of five sympatric terns at a sub-tropical island in the eastern Indian Ocean. *Journal of Zoology, London* 259: 219–230.

TRAYLER, K.M, BROTHERS, D.J., WOOLLER, R.D. and POTTER, I.C. 1989. Opportunistic foraging by three species of cormorants in an Australian estuary. *Journal of Zoology, London* 218: 87–98.

VALESINI, F.J., POTTER, I.C., WILDSMITH, M.D., HOURSTON, M., PLATELL, M.E., COEN, N.J., SCHAFER, L.N., SEIDEL, S.T. and WHITEHEAD, A.L. 2003. The importance to fish species of the various habitats in nearshore marine waters of south-western Australia. FRDC Final Report (2000/159).

VANDERKLIFT, M.A. and JACOBY, C.A. 2003. Patterns of fish assemblages 25 years after major seagrass loss. *Marine Ecology Progress Series* 247: 225–235.

VAUGHN, R.L., SHELTON, D.E., TIMM, L.I., WATSON, L.A. and WÜRSIG, B. 2007. Dusky dolphin (*Lagenorhynchus obscurus*) feeding tactics and multi-species associations. *New Zealand Journal of Marine and Freshwater Research* 41: 391–400.

WELLS, R.S., IRVINE, A.B. and SCOTT, M.D. 1980. The social ecology of inshore odontocetes. pp 263–317 in *Cetacean Behaviour: Mechanisms and Processes*, L.M. Herman (ed). John Wiley *and* Sons, New York, USA.

WOOLLER, R.D. and DUNLOP, J.N. 1981. Itinerant breeding by Pied Cormorants on Carnac Island, Western Australia. *Corella* 5: 97.

WOOLLER, R.D., DUNLOP, J.N., KLOMP, N.I., MEATHREL, C.E. and WIENECKE, B.C. 1991. Seabird abundance, distribution, and breeding patterns in relation to the Leeuwin Current. *Journal of the Royal Society of Western Australia* 74: 129–132.

WÜRSIG, B. and WÜRSIG, M. 1979. Behavior and ecology of the bottlenose dolphin, *Tursiops truncatus*, in the south Atlantic. *Fishery Bulletin* 77: 399–412.